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Article

Tear Film Break-Up Time before and after Watching a VR Video: Comparison between Naked Eyes and Contact Lens Wearers

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Abstract: The impact of viewing VR videos using a head-mounted display (HMD) on tear film dynamics is examined by comparing the viewing experience of individuals using their naked eyes with that of viewers wearing contact lenses. While the impact of VR on eye dryness has been studied, there is limited research on the risks for contact lens wearers. This study aims to investigate eye dryness associated with VR use in individuals wearing soft contact lenses. Seventeen adults in their 20s (7 male, 10 female) with uncorrected visual acuity of 0.8+ participated. The non-invasive tear film break-up time (NIBUT) was assessed before and after a 20 min VR video session under two conditions: with and without soft contact lenses. The results indicated a decrease in the initial tear film break-up time and an increase in the average tear film break-up time when viewing with naked eyes, whereas viewing with contact lenses led to decreases in both parameters, with statistically significant changes observed. Although the alteration in the tear film break-up time was insignificant during VR video viewing with naked eyes, the tear film stability of individuals wearing soft contact lenses tended to decrease. Caution is advised when using soft contact lenses during VR video sessions to mitigate potential eye dryness.

Keywords: virtual reality; contact lenses; eye dryness; non-invasive tear film break up time

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1. Introduction

Dry eye syndrome is a condition characterized by the disruption of ocular surface homeostasis due to an inadequate aqueous tear layer, excessive tear evaporation, and impaired tear drainage, which can lead to corneal and conjunctival damage, presenting symptoms such as ocular dryness, foreign body sensation, pain, and visual impairment [1]. With aging, the prevalence of dry eye syndrome continues to increase [2], particularly among women and the middle-aged and elderly populations [3]. However, due to factors such as increased usage of digital devices, even younger individuals, including those in occupations involving prolonged computer use and contact lens wearers, report discomfort [4].

Contact lens wearers, in particular, are susceptible to developing dry eye syndrome [5]. Because contact lenses are in direct contact with the eye surface, improper usage can decrease ocular moisture and induce symptoms associated with dry eyes [6]. Additionally, the deposition of tear proteins on contact lens surfaces can cause discomfort, dryness, reduced lubrication, and decreased oxygen permeability, which lead to further ocular complications [7].

The advent of the Fourth Industrial Revolution has seen the integration of related technologies such as virtual reality (VR) and augmented reality (AR) into various fields including education, healthcare, and marketing [8]. However, a study by Kim et al. [9] found that VR usage can decrease the frequency and speed of blinking to potentially impacting conditions such as keratitis and dry eye syndrome [10]. Accordingly, technology that can induce eye blinking in VR viewing situations is also being developed [11]. In addition, the prolonged use of VR head mounted displays (HMDs) has been reported to result in dry eyes by reducing the number of eye blinks and accelerating tear evaporation due to heat generated by the display in an environment in which air circulation is limited. This could lead to subjective symptoms of dry eyes. Based on the outcome of the score (OSDI) questionnaire, it was reported that the aforementioned symptoms increased when using VR devices [12]. Prolonged use of digital screens, known as visual display terminals (VDTs), has become common, leading to increased visual complaints like eye strain and dryness. The ocular symptom most commonly reported was a sensation of burning (58.3%), followed by feelings of dryness (51.5%), blurred vision (44.6%), and redness (40.8%). Dryness emerged as the most prevalent severe symptom, with burning and dryness being the primary manifestations of dry eye syndrome [13].

On the other hand, Turnbull et al. [14] reported that VR may be effective for treating dry eye syndrome by increasing the temperature around the eyes due to the heat generated by the display in an environment isolated from the surroundings. Based on conflicting studies regarding VR's impact on dry eye syndrome, this research aims to investigate the effects of VR viewing on eye dryness in individuals wearing soft contact lenses. Specifically, this study examines the impact of viewing VR videos on tear film stability by comparing the tear film break-up times of individuals using their naked eyes versus those wearing contact lenses. The Results section will present detailed findings on the changes in initial and average tear film break-up times before and after VR viewing under both conditions. Specifically, Section 3.1 will discuss the changes observed when participants viewed VR videos with their naked eyes, while Section 3.2 will focus on the changes when participants wore contact lenses. Additionally, Section 3.3 will compare tear film break-up times across two different days to establish a baseline for natural variability. In this study, we aimed to investigate changes in the tear film break-up time, a discriminating diagnostic factor for dry eye syndrome, when viewing virtual reality videos in both external and enclosed environments while wearing an HMD type of VR device with or without soft contact lenses.

2. Subjects and Methods

2.1. Subjects

The study involved a total of 17 adults in their twenties, comprising 7 men and 10 women, with an average age of 22.12 ± 1.41 years. Each participant contributed data from both eyes, resulting in a total of 34 eyes being examined. All participants had no history of ocular diseases and possessed unaided visual acuity of 0.8 or higher.

2.2. Experimental Devices

In this study, a smartphone (LM-G710N, LG Electronics, Seoul, Republic of Korea) was mounted onto an HMD VR device (VR BOSS Xtrek, SmartPia, Yongin, Republic of Korea) to view VR content. The smartphone had a display size of 6.1 inches, a diagonal measurement of 154.7 mm, and a resolution of 3120 × 1440 pixels, with a pixel density of 564 ppi. The VR device could support a maximum smartphone size of 195 mm × 88 mm. The distance between the eyes and the lenses could be controlled. The distance to the optical centers could be also controlled in the range of 60–70 mm. The lenses on the VR device were aspherical, had +17 D spherical refraction, and provided a field of view of approximately 100°.

The noninvasive break-up time (NIBUT) measurements before and after VR viewing were conducted using the Instrument for dry eye assessment (IDRA, SBM, Orbassano, Italy) (Figure 1). The SBM device facilitates the assessment of tear film stability and regularity by mapping the tear film geometry on the cornea. It measures both the initial tear film break-up time, from the completion of a full blink to the onset of tear film disruption, and the average tear film break-up time until complete tear film destabilization. The tear film break-up time (TBUT) test is useful for diagnosing dry eye syndrome and can also aid in diagnosing other eye conditions such as keratitis, conjunctivitis, and eyelid disorders. The initial TBUT is the interval between a complete blink and the first appearance of a dry spot or discontinuity on the tear film. It is typically measured in seconds and reflects the stability of the tear film immediately after the eye opens. The average tear film break-up time is the mean time it takes for dry spots to appear on the tear film over multiple measurements. This average provides a more comprehensive assessment of the tear film stability, rather than relying on a single instance. A TBUT of 10 s or more is considered normal, while a TBUT of 5 s or less may indicate dry eye syndrome. Both of these measurements are used in diagnosing and managing dry eye syndrome and other ocular surface disorders. A shorter TBUT indicates a less stable tear film and potential dry eye problems. Additionally, the SBM device furnishes researchers with extensive data and offers an automated assessment of tear film stability sans fluorescein.

Figure 1. Measurement of tear film breakage time using Idra.

2.3. Methods

The VR videos were viewed for 20 min with naked eyes and while wearing color contact lenses without power (Figure 2).

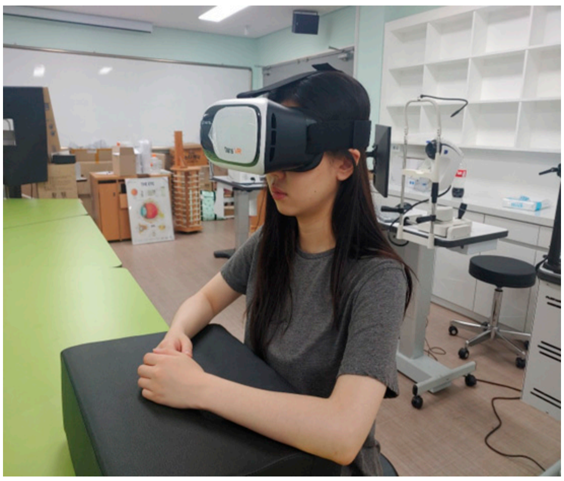

Figure 2. Subject watching VR.

To prevent the experimental results from being influenced by the VR viewing and tear film examination stimuli, the experiment was conducted over two days, with one day dedicated to conducting the experiment with naked eyes and another day with participants wearing color contact lenses. The impact of glasses was minimized by selecting participants with an unaided visual acuity of 0.8 or higher, and all participants wore color contact lenses without power. To minimize the influence of the experiment order, participants were divided into two groups: one that wore contact lenses first and another that experimented with unaided eyes first. The tinted soft contact lenses (DNA Shiny star, MTPR, Daejeon, Republic of Korea) used in this experiment were composed of methafilcon A material, and the experiment was conducted after a 5 min period of central stabilization following lens insertion.

The experimental procedure involved first measuring the initial and average non-invasive tear film break-up time while viewing with naked eyes, followed by watching videos for 20 min using the VR HMD, and finally measuring the initial and average tear film break-up time again. The following day, the initial and average tear film break-up times, when viewing with naked eyes, were measured first, after which the participants watched VR videos for 20 min while wearing color contact lenses. The contact lenses were then removed to enable the initial and average tear film break-up times to be measured again (Figure 3). To ensure the reliability of tear film break-up time measurements, all measurements were conducted three times, and they were repeated for each participant by the same examiner. The experimental environment maintained a constant temperature of 22 ± 2 °C and a relative humidity level of 50 ± 5% throughout the study to ensure consistency.

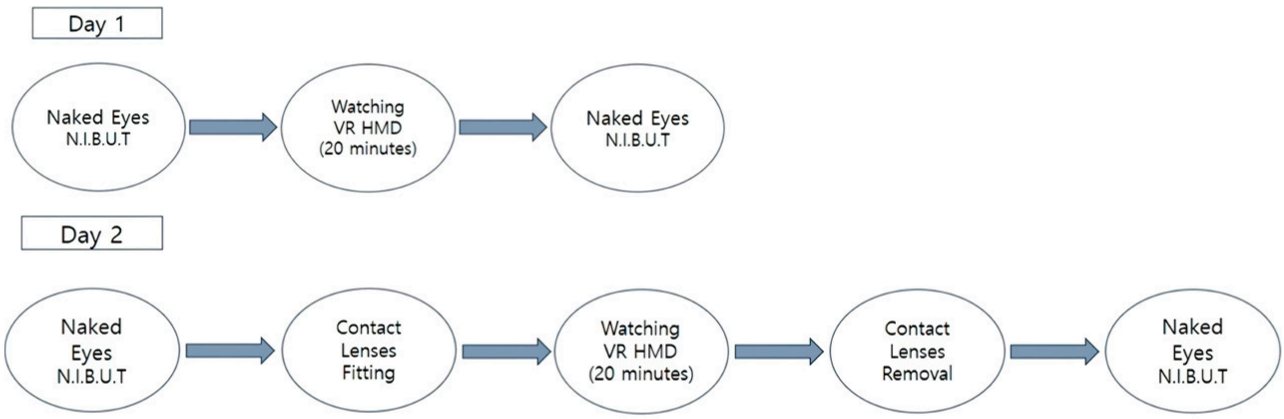

Figure 3. Experimental procedure.

2.4. Statistical Analysis

In this experiment, statistical analysis was conducted using SPSS 20.0 to compare the changes before and after watching VR videos through paired *t*-tests. We compared the tear film break-up time before and after the condition with uncorrected eyes or wearing contact lenses and further verified whether there was a difference in the state before the experiment and whether there was a difference in the tear film break-up times before the experiment on Day 1 and Day 2. For each test, a significance level (*p*-value) of 0.05 or less was considered as indicating a significant difference, with a confidence level of 95%.

3. Results

3.1. Changes in Tear Film Break-Up Time: Viewing with Naked Eyes

The initial tear film break-up time with the naked eyes was 5.09 ± 1.08 s before watching VR and 4.83 ± 1.85 s after watching VR, a decrease of approximately 0.26 s. However, this change was not statistically significant (Figure 4). Similarly, the average tear film break-up time was 9.98 ± 3.24 s before watching VR and 10.28 ± 4.39 s after watching VR, indicating an increase of approximately 0.3 s. Again, the change was statistically insignificant (Figure 5).

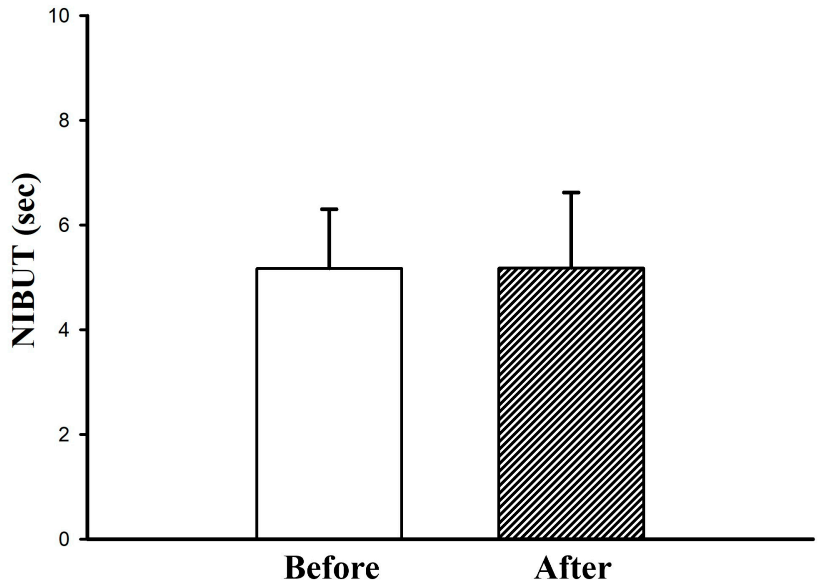

Figure 4. Initial tear film break-up time before and after watching the VR video with the naked eye.

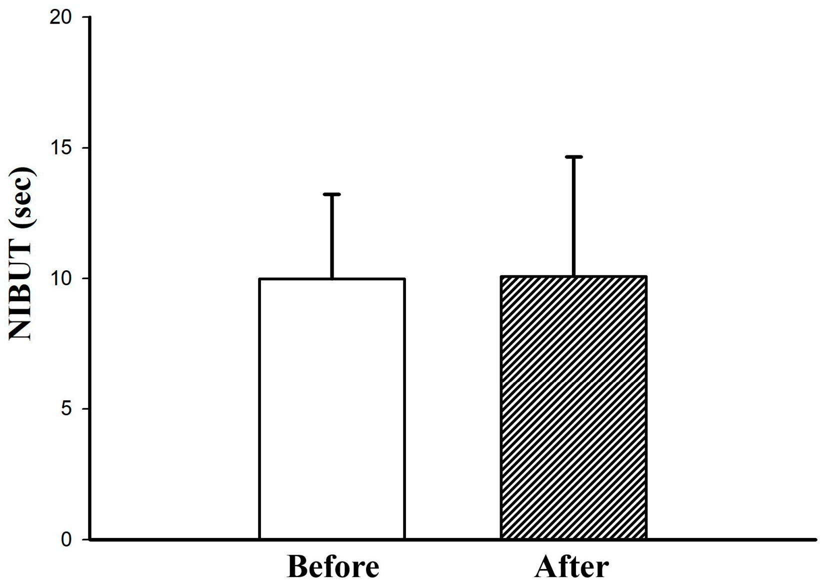

Figure 5. Average tear film break-up time before and after watching the VR video with the naked eye.

3.2. Changes in Tear Film Break-Up Time: Viewing while Wearing Contact Lenses

Before inserting the contact lenses, the initial tear film break-up time when viewing with the naked eyes was 4.71 $\pm$ 1.22 s before watching VR. After watching VR while wearing the contact lenses, the tear film break-up time was 4.65 $\pm$ 0.98 s, a decrease of approximately 0.06 s. However, this change was not statistically significant (Figure 6).

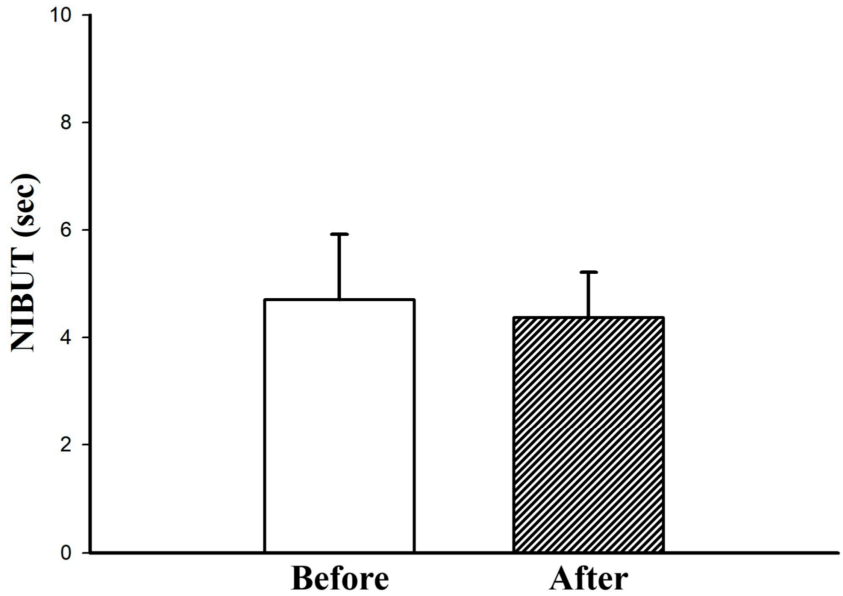

Figure 6. Initial tear film break-up time before watching the VR video with the naked eyes compared with after watching the VR video while wearing contact lenses.

Regarding the average tear film break-up time, it was 8.90 ± 3.47 s before watching VR with the naked eyes. After watching VR while wearing contact lenses, the average tear film break-up time decreased to 8.24 ± 2.76 s, showing a decrease of approximately 0.66 s. This change was statistically significant ($p < 0.05$) (Figure 7).

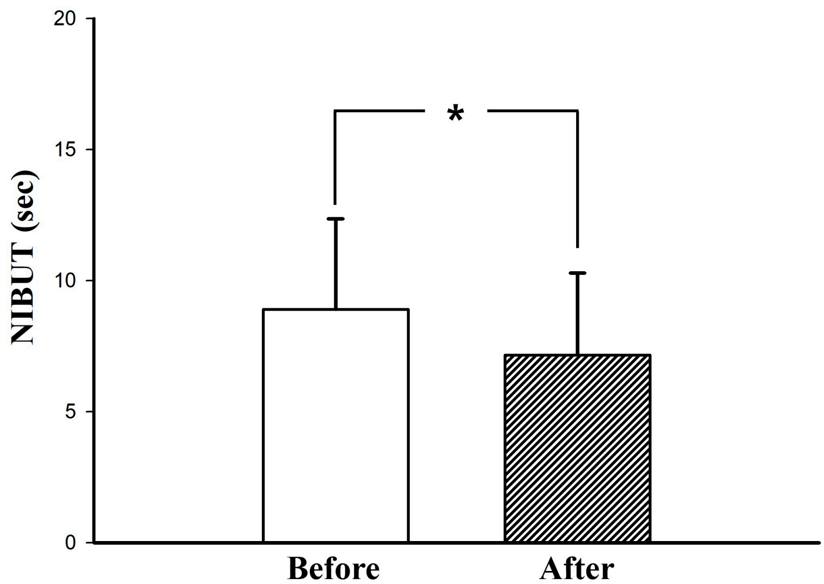

Figure 7. Average tear film break-up time before watching the VR video with the naked eyes compared with after watching the VR video while wearing contact lenses. * Statistically significant difference from the baseline value ($p < 0.05$, paired *t*-test).

3.3. Changes in Tear Film Break-Up Time before Watching VR Videos with the Naked Eyes

On the first day of the experiment, the initial tear film break-up time when viewing with the naked eyes was 5.09 ± 1.08 s. On the second day, before inserting the color contact lenses, the initial tear film break-up time when viewing with the naked eyes was 4.71 ± 1.22 s. Thus, the initial tear film break-up time differed by approximately 0.38 s between the two days (Figure 8). However, this difference was statistically insignificant.

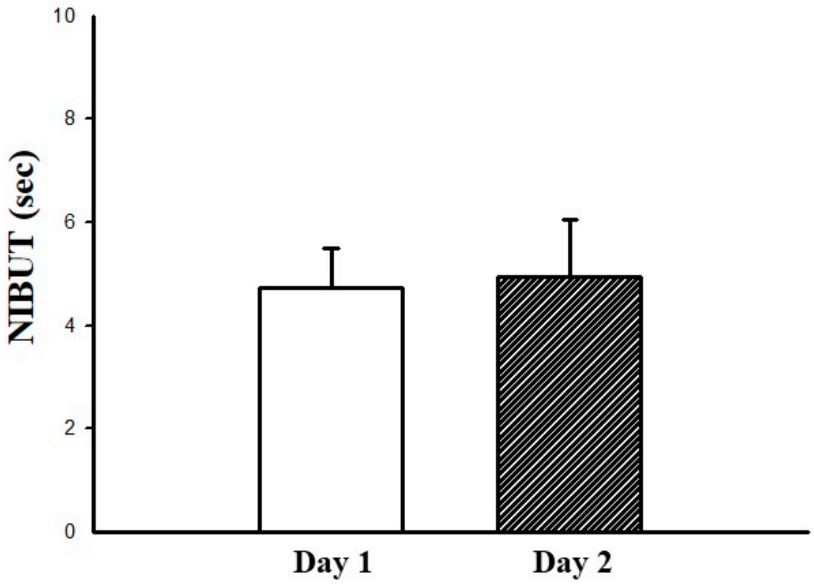

Figure 8. Initial tear film break-up time before watching the VR video with the naked eye: comparison between the first and second days.

Regarding the average tear film break-up time, it was 9.98 ± 3.24 s on the first day and 8.90 ± 3.47 s on the second day. Despite the difference of approximately 1.08 s between the two days, it was not statistically significant (Figure 9).

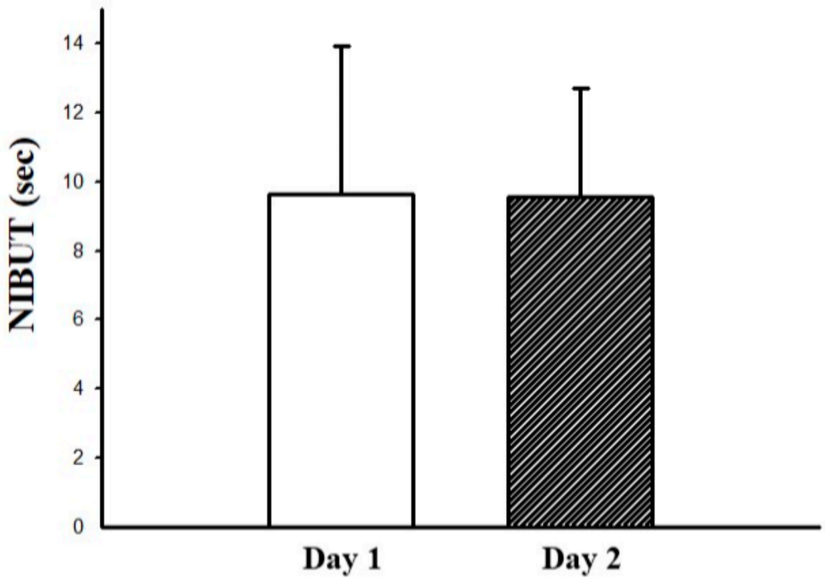

Figure 9. Average tear film break-up time before watching the VR video with the naked eye: comparison between the first and second days.

4. Discussion

Non-invasive tear film break-up time (NIBUT) is a commonly used test to assess tear film stability. However, studies suggest variability in NIBUT measurements depending on the instrument used and the subjects tested [15]. Recent investigations have assessed the repeatability and reliability of NIBUT using two different devices: the Keratograph 5M (K5M) (Oculus®, Arlington, WA, USA) and the Infrared Diode-Optical Society Analyzer (IDRA-OSA) (SBM Sistemi, Orbassano, Italy). The findings suggest good repeatability and reliability in the control group, indicating that for individuals with a healthy tear film, repeated NIBUT measurements using either K5M or IDRA-OSA produce consistent results [16]. Another study found that a new, non-invasive ocular surface analyzer (IDRA) effectively identifies dry eye disease (DED) and shows good agreement with existing diagnostic methods. This suggests that IDRA could be a valuable tool for initial DED screening and guiding treatment decisions in outpatient settings [17].

The initial and average tear film break-up times are crucial metrics of tear film stability, each reflecting distinct aspects. The initial tear film break-up time denotes the moment when the tear film begins its first break-up, which is pivotal for detecting early indications of tear film instability. Conversely, the average tear film break-up time provides the mean break-up time occurring across the entire corneal surface, thereby offering a comprehensive understanding of tear film stability across diverse regions [18]. The changes between the respective initial and average tear film break-up times while watching VR videos with the naked eyes were not statistically significant. However, when wearing contact lenses, both the initial and average tear film break-up times changed, with a statistically significant change observed for the average tear film break-up time. Previous studies have shown that short-term use of a virtual reality headset with naked eyes does not reduce tear film stability, but it was determined that further research is needed for long-term use or in dry environments such as in dry-eye patients. In this study, the change in tear film stability under unaided eyes was not significant, but when a dry environment was created by wearing contact lenses, it was observed that the average tear film break-up time decreased, thus affecting overall tear film stability [14,19].

The reason for the shorter tear film destruction time is that the viewing distance of the VR HMD allows for 360-degree viewing compared to other digital devices, and the surrounding environment is excluded from the view, which may have affected the number and speed of tears due to the increased sense of immersion. The heat generated by the display in an environment where circulation is limited is also considered likely to accelerate the evaporation of tears to create a dry environment. Additionally, the heat generated by the display in an environment with limited air circulation may promote tear evaporation and the formation of a dry environment. However, it is worth noting that some studies suggest that appropriate increases in the internal temperature of VR HMDs may have therapeutic effects on dry eye syndrome.

Sensations of dryness in the eyes are commonly experienced in dry environments and are exacerbated by factors such as contact lens wear and exposure to wind and atmospheric pollutants. Contact lens wearers may experience instability in the tear film due to protein deposition, the lens material, and fitting issues, all of which would give rise to increased sensations of dryness.

The results of this experiment indicate that changes in the tear film break-up time were significant only when participants were wearing soft contact lenses while viewing the VR video, whereas the changes when viewing with the naked eyes were insignificant. Further experiments with variations in the viewing time, types of video content, and detailed experimental conditions such as the temperature and humidity may be necessary to fully understand the effects of VR video viewing on the tear film dynamics.

By focusing on tear film stability and eye dryness in contact lens wearers during VR use, this study addresses a critical gap in the literature. This approach provides new insights into how VR affects this specific population. Furthermore, a thorough comparative analysis is presented, examining initial and average tear film break-up time (TBUT) before and after VR use. The significant differences observed when contact lenses are worn offer valuable data for understanding the ocular impact of VR use under different conditions. These findings have practical implications, highlighting the necessity for caution among contact lens wearers and suggesting directions for developing more eye-friendly VR systems. This focus on user safety and comfort can benefit VR stakeholders, including device manufacturers, healthcare providers, and, ultimately, users themselves, promoting enjoyable and comfortable VR experiences. Advanced control methods, optimal feedback mechanisms, and innovative sensor integrations could enhance the safety and user experience in VR environments, thereby mitigating the issues observed with tear film break-up times in our study. Future research could explore these technological integrations to develop more eye-friendly VR systems, ensuring user comfort and health during prolonged VR sessions [20–22].

5. Conclusions

This study involved an investigation of changes in the tear film break-up time when wearing soft contact lenses while viewing virtual reality (VR) videos using head-mounted display (HMD) type VR devices compared to viewing with the naked eyes. The comparison aimed to discern the effects of external environmental conditions versus excluded environments on the tear film dynamics, a factor that affects the diagnosis of dry eye syndrome. The tear film break-up time did not change significantly after watching VR videos with the naked eyes for approximately 20 min using VR HMDs. However, the initial and average tear film break-up times for wearers of color soft contact lenses tended to decrease. Therefore, caution is warranted when watching VR videos while wearing color soft contact lenses, as they may enhance eye dryness compared to naked eyes. Further experiments will be conducted under different conditions, including rigid gas permeable lenses, and additional variables such as blink frequency will be investigated to gain a comprehensive understanding of the impact of VR on tear film dynamics.

Author Contributions: Conceptualization, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); methodology, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); resources, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); data curation, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); writing—original draft preparation, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); writing—review and editing, H.K. (Hyunjin Kim), M.G. and H.K. (Hyungoo Kang); visualization, supervision, H.K. (Hyungoo Kang). All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The Institutional Review Board of Catholic kwandong University approved the study (CKU-23-01-0403), and all studies followed relevant guidelines. All participants provided written informed consent and were naïve to the purpose of the experiment.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. The study adhered to ethical guidelines, ensuring that participants were fully informed about the nature and purpose of the experiment and that their participation was voluntary.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request. Due to privacy and ethical restrictions, not all data can be publicly shared, but anonymized data can be provided for academic and research purposes.

Conflicts of Interest: The authors declare no conflicts of interest.

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